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IR ALGORITHM DEVELOPMENT FOR FIRE AND FORGET PROJECTILES.(U)
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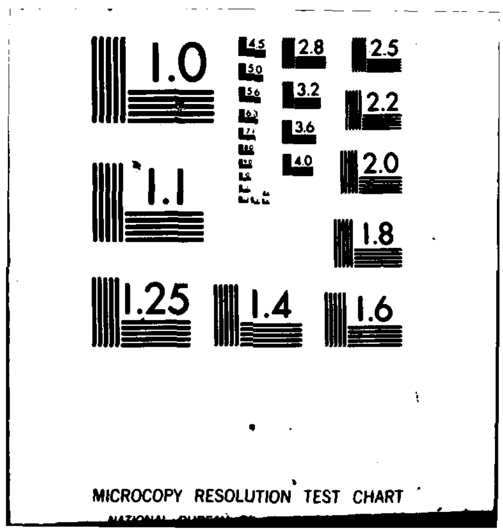
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2.5
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MICROCOPY RESOLUTION TEST CHART

# IR Algorithm Development for Fire and Forget Projectiles

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1. INTRODUCTION: ARRADCOM has under contract, on the Advanced Indirect Fire System (AIFS) Program, several contractors who are attempting to solve the problem of autonomous detection of military targets, primarily armored vehicles. The contractors are prepared to analyse data from the background as well as targets in their seeker's field of view to develop algorithms designed to distinguish the targets from the background. Several of the sensing approaches collect and analyse reflected MMW (Radar) energy, while several other approaches depend upon receiving the targets' radiated and/or solar reflected infrared (IR) energy. This paper addresses algorithms currently being used to operate on this IR energy in the 3-5u and 8-12u passbands. It should be recognized that many of the IR detection algorithm techniques are also applicable to other forms of energy.

The Precision Munitions Branch of the Munitions Systems Division of the Large Caliber Weapon Systems Laboratory has undertaken its own independent analysis of the contractors' algorithms by programming them on its in-house computer. These algorithms are then run against stored IR images of actual foreign tanks to determine the capabilities and limitations of each algorithm. Since most contractors have several versions of their proprietary algorithms which they are evaluating to determine which are most effective we have had to evaluate a considerable number of variations. Additionally we have programmed algorithms from other sources evaluating them against the same IR data set. Finally we have indpendently modified and combined various algorithms to attempt to improve their performance.

The in-depth knowledge of the contractors' algorithms gained by evaluating hundreds of IR scenes has allowed us to devise and conduct tower and captive flight tests which have verified the algorithm's performance under conditions approaching its useful limits.

2. ALGORITHMS USED FOR ARMORED TARGET DETECTION: An algorithm is a set of logical rules or mathematical instructions used to solve complex problems. The problem of autonomous target detection most complex because no theoretical model of the background clutter has been found to predict the actual observed data over the range of environmental conditions typically found to occur. Additionally the various target conditions i.e. operating history, viewing aspects, and target types combined with the atmospheric variations produce an unmanageably large set of data.

The most common discriminats used for autonomous detection of targets include: the target's radiant intensity, the variability of the intensity and the spatial extent of the energy. Algorithms should, in addition to finding military targets, reject other objects (including active countermeasures) which are: too hot (a flare or already burning targets), too small (rocks, sheds, flares), too large (buildings, ponds, trees) and the wrong shape (roads, utility lines, natural clutter).

The various algorithms being implemented by the several contractors are quite unique in their details. However several general features can be used to distinguish one from another. Typical operators which algorithms use to process the thermal signature are: Matrix Multiplication, First Moment (M1), Second Moment (M2), Cross Exceedance, Spatial Size Discrimination, Segmentation or Variability, and Edge and/or Shape Finders. It should be noted that several of these operators, although different in their methods, obtain measures of the targets which are really quite similar. For example, several of the matrix operators as well as the cross operator are used solely to obtain spatial (size) discrimination. Not suprisingly, therefore, most seekers collect IR data in a manner which preserves the spatial properties of the target and its background. The simplest method (in theory) of collecting this data is with a large focal plane array (FPA) of detector elements (pixels) since all spatial information is present simultaneously. Typically 32 X 32 or 64 X 64 pixels of information are processed for each "snapshot" or picture. Figure 1 shows a subset of a larger array of pixels, along with a matrix multiplication spatial algorithm suggested by Parenti at MIT (1). The target's thermal energy is assumed to be located at the center of a 9 pixel area of the FPA. The thermal intensity of each background pixel is multiplied by 1/16 while the single target pixel is multiplied by 1. All other pixels are ignored or multiplied by zero. The sum of all 17 pixels is used as a merit function which can be seen to generate a zero for a uniform scene and some number larger than zero for a target. This operator is used once for each different target pixel location.

An AIFS contractor with a focal plane array sensor is using a much more complex scene analysis to distinguish targets from the

background. Sizing this system for use with higher resolution optics, this algorithm calculates and compares the average and standard deviation of the background radiant energy. Figure 2 defines those target and background areas. Each target pixel is then compared to the background, using a first moment type calculation. This process is repeated for all possible target locations, just as the matrix multiplication does. The merit function thus derived is used to locate probable target locations. These locations are handed over to a second algorithm which segments that portion of the scene into areas of like intensity. The number of pixels belonging to segments lying solely within a target sized area is used as the final discriminant. This final segmentation technique may also provide a measure of the target's variability.

A non-imaging seeker, operating on a scanning linear array of 12 pixels can be used with a shift register memory to obtain enough spatial data to find targets. A second moment (M2) operator is used in this algorithm is similar in form to a first moment except that the pixel values are squared. In each nine pixel area (three adjacent pixels of the array sampled three times while the array rotates) an M2 value is computed. An M2 or variance map of the scene is thus constructed in the shift register memory. In this M2 domain a target sized area is compared to like sized areas. When the M2 values in the target area are larger by some threshold than the other areas a target is detected.

A cross exceedance algorithm, although subsequently found to be inefficient at finding targets when used alone, may be used as a pre-screening algorithm. Figure 3 demonstrates how the cross exceedance is used as a discriminant. The exceedance algorithm is satisfied if the center pixel is larger (by some threshold) than each of the pixels indicated by being blackened in any of the nine cross arrays shown.

Spatial algorithms, when used alone, lead to poor overall performance due primarily to false targets. These algorithms search for areas which have the same thermal shape as a target. The primary difficulty with this approach is that the shape of the IR image of a target is not a constant nor is it similar to the visual image except under special circumstances. This is illustrated in the following section.

3. IR IMAGES IN THE DATA SET: Several sources of IR imagery exist in the community. They include NVL, MIT, ERIM and TABILS. Much of the TABILS data was taken at Eglin Air Force Base, Florida with a foreign tank as the target. A visible spectrum photograph is available for each digitized IR image scene. A photograph of a typical scene is shown in Figure 4. An IR image constructed from the TABILS data of the identical scene is shown in Figure 5. One can see from this image that

the IR shape is not at all similar to the visual shape. (Note that registration lights - heat lamps - are placed in the scene to aid in locating the target). Another illustration of this thermal shape difference can be seen in Figure 6. These photos show a top view of the same target under two operating conditions (top exercised, bottom stationery).

4. EXAMPLES OF ALGORITHMS APPLIED TO IR DATA: The IR image shown as shades of grey in Figure 5 is shown in Figure 7 where different characters represent different intensities. The scale is such that punctuation marks and symbols are the lower values followed by the numbers (in order) with the letters (in order) being the higher intensity. The asterisk is the highest value. This scene operated upon by the M2 algorithm is shown in Figure 8. Here one can notice that the small heat lamps become larger and are of the highest level. Figure 9 shows the result of applying the cross exceedance pre-screener and a size discriminant to the M2. Note that many of the false alarms have been eliminated, and if a threshold at the "C or D" level were chosen it would result in a scene which consists of just the target and the two heat lamps. One can then easily eliminate the heat lamps by using a T-max or color ratio technique.

The MIT algorithm operating on this same scene is shown in Figure 10. It does not make the heat lamps bloom as the M2 operator does, but it has problems with separating the target from the background. A variant of this algorithm, using the MIT matrix to operate on a M2 map significantly reduces the false alarms.

The first moment algorithm "found" three potential targets in this sample scene shown in Figure 11. Figure 12 illustrates the results of the segmentation algorithm. The shaded pixels indicate those segments which lie totally within a target sized window. This is the target area.

5. RESULTS OF COMPUTER ANALYSIS AND/OR CAPTIVE FLIGHT TESTS OF SELECTED ALGORITHMS: The most successful sets of algorithms are those demonstrated in Figure 10. Not only did this combination of algorithms successfully find the target in almost all IR data scenes it also performed remarkably well during actual captive flight tests. Problem areas which surfaced during flight tests were primarily due to false targets which had not been seen in the IR data sets.

Computer analysis of the algorithms using the first moment with spatial processing and segmentation indicated several drawbacks. Many targets were missed while other background areas were selected as potential targets. Also the target areas chosen often would include only part of the target while including a considerable portion of the

background. Ground tests of a seeker using these algorithms confirmed the existance of the problem areas predicted by the computer analysis and thus captive flight tests were not conducted.

6. CONCLUSIONS: Various algorithms have been evaluated against several hundred IR scenes. Some of these algorithms have been found to be more successful at autonomous target detection than others. Generally, those which use the second moment operator find more real targets. Those using the first moment are more successful when they use a second algorithm to segment the image. LCWSL, using these analyses, has obtained valuable insight into the capabilities and limitations of not only the algorithms used by the AIFS contractors but also of other contractors who have proposed algorithms to the Government. The ability to captive flight test only seekers with the most promising algorithms provides the Army the opportunity to conserve valuable resources. Thus the usefulness of predicting probable success or failure of target detection algorithms from a computer analysis using various IR data sources has been demonstrated. Additional insights into algorithm performance allows the Government to better specify future autonomous seekers as well as to design test programs which will accurately predict the system performance of the fielded weapon system.

7. REFERENCES:

1-Parenti, R., Otazo, J. and Tung, E. "The Design of a Digital Filter for Resolved Stochastic Targets" Presented at 1980 National IRIS Meeting.

MATRIX MODIFICATION ALGORITHM FROM M.I.T.

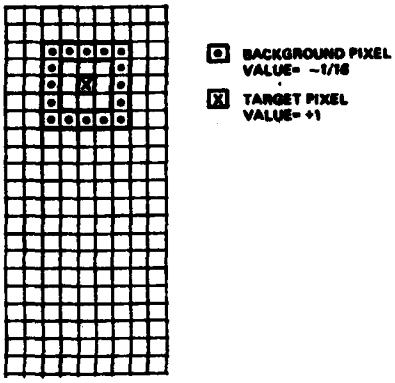


FIG 1

TARGET AND BACKGROUND DEFINITIONS AND IMAGING SEEKER ALGORITHM

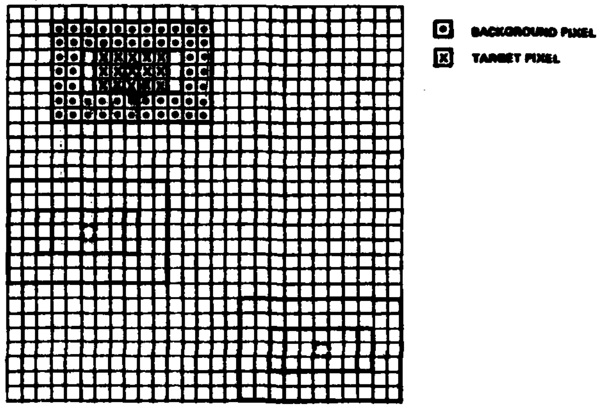


FIG 2

## CROSS EXCEEDANCE ALGORITHM

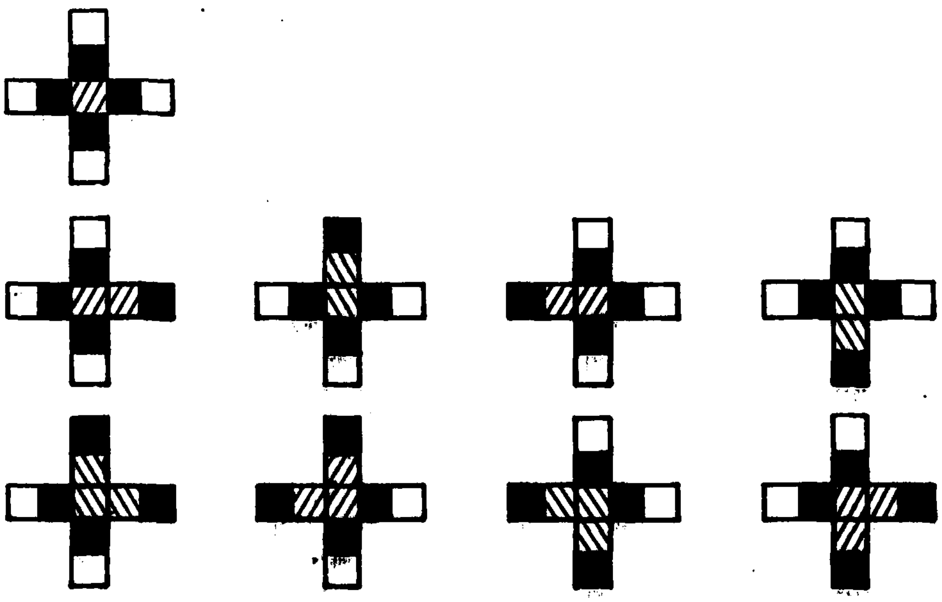

FIG 3

PHOTOGRAPH OF TABILS SCENE

FIG 4

FIG 5
IR IMAGE OF TABILS SCENE

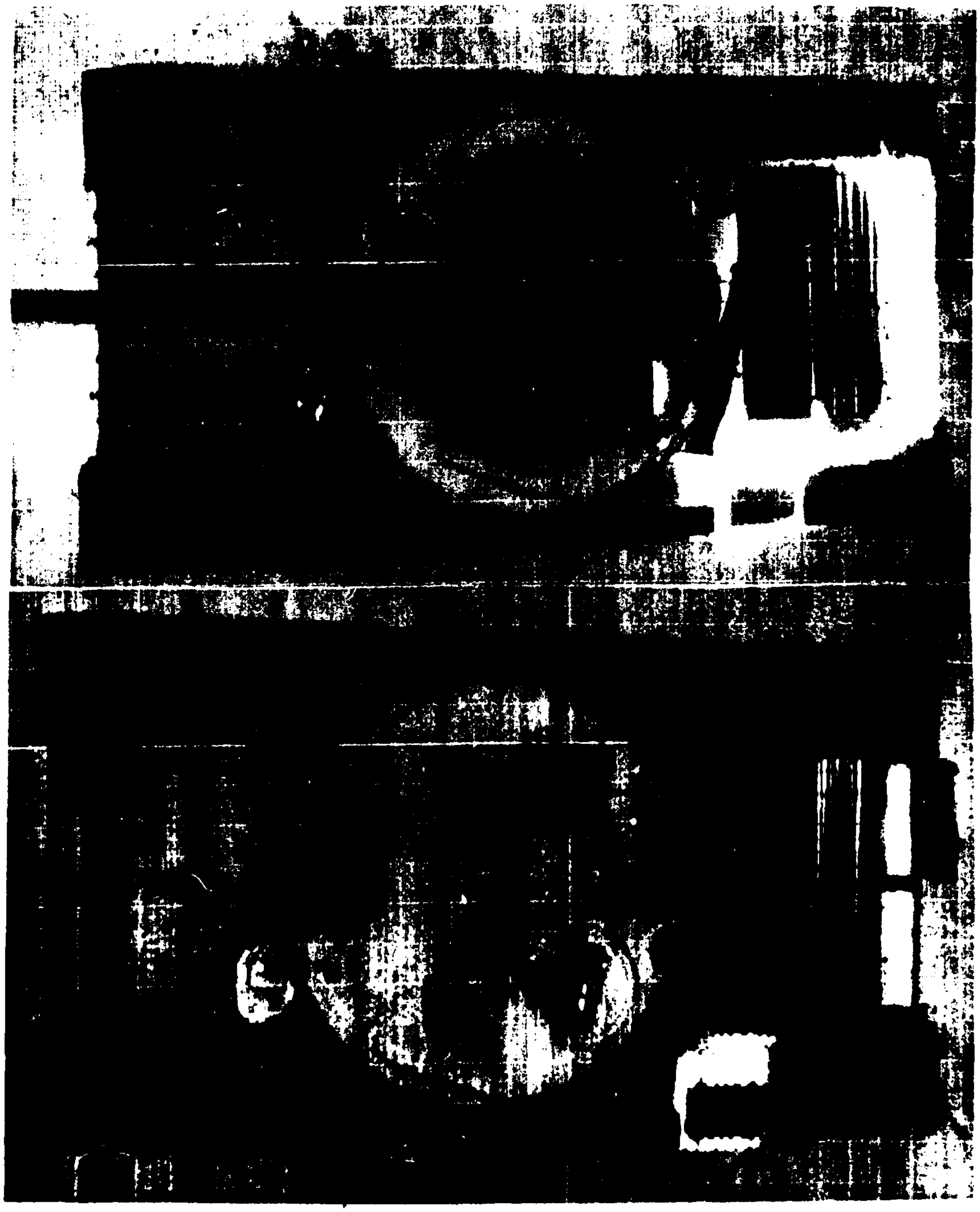

FIG 6 THERMAL IMAGERY OF A TYPICAL TANK, (TOP-EXERCISED, BOTTOM-IDLE)

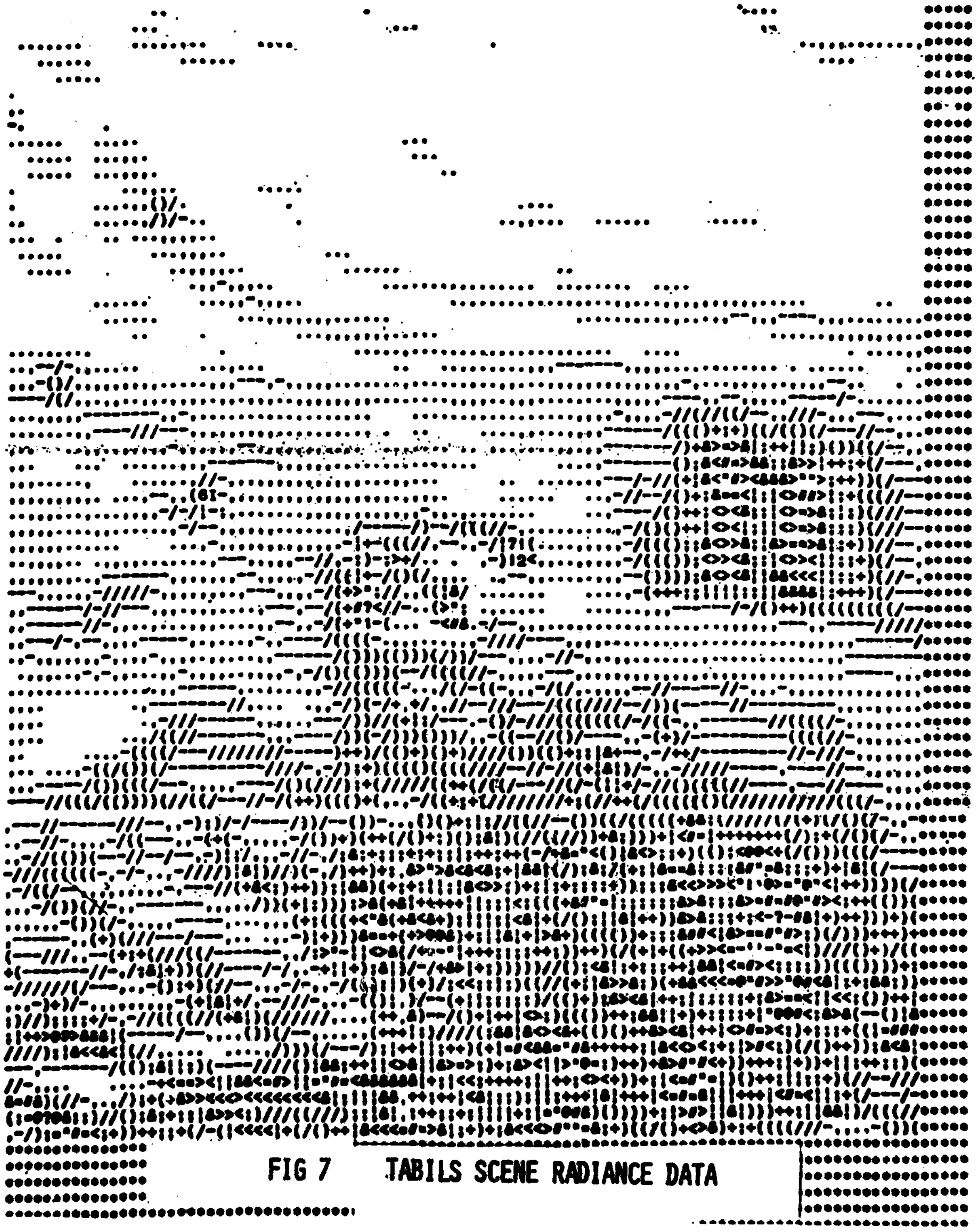

FIG 7 TABILS SCENE RADIANCE DATA

TABILS SCENE FIG 8

FIG 9 TABILS SCENE-GATED M2 + SPATIAL

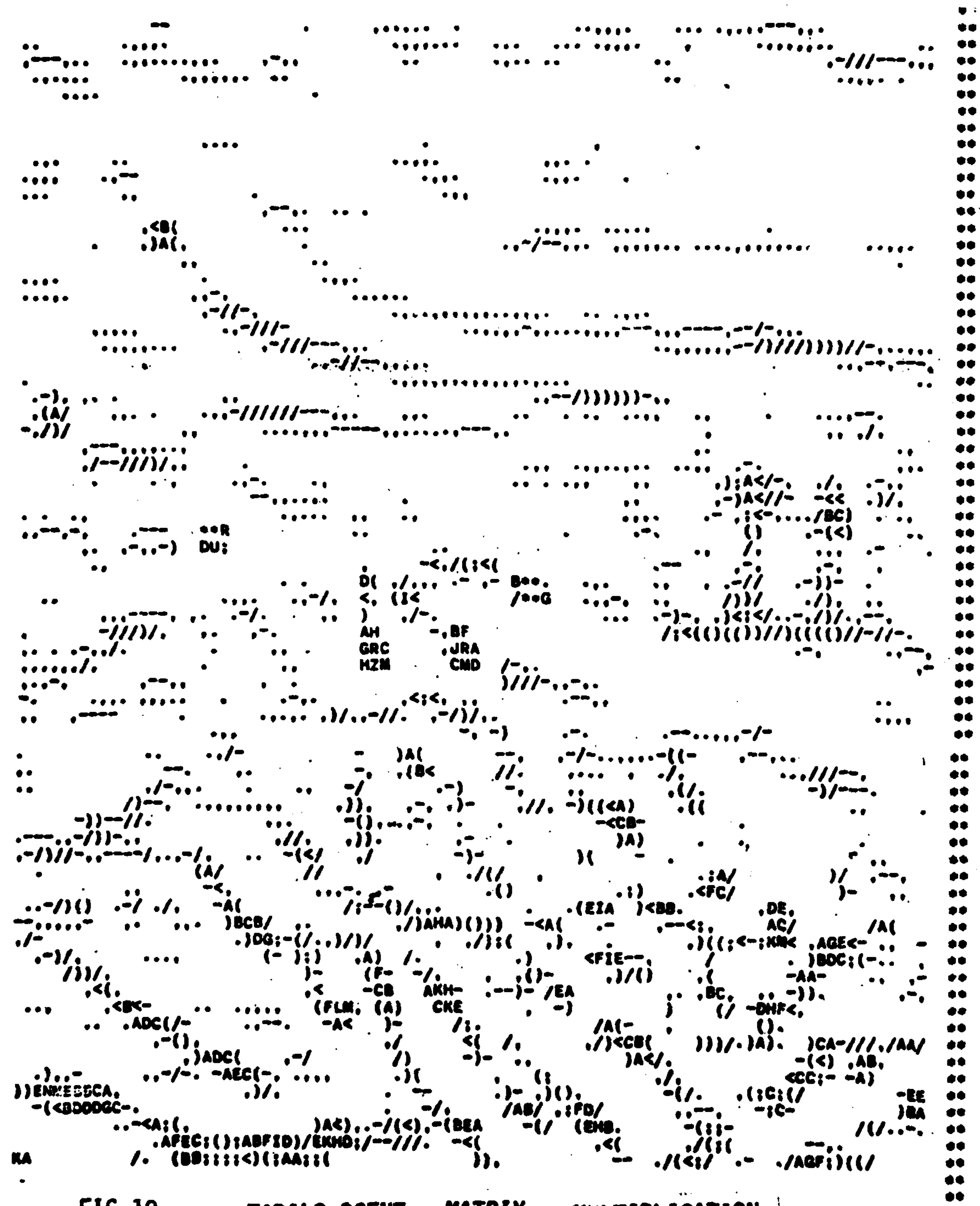

FIG 10 TABILS SCENE - MATRIX MULTIPLICATION

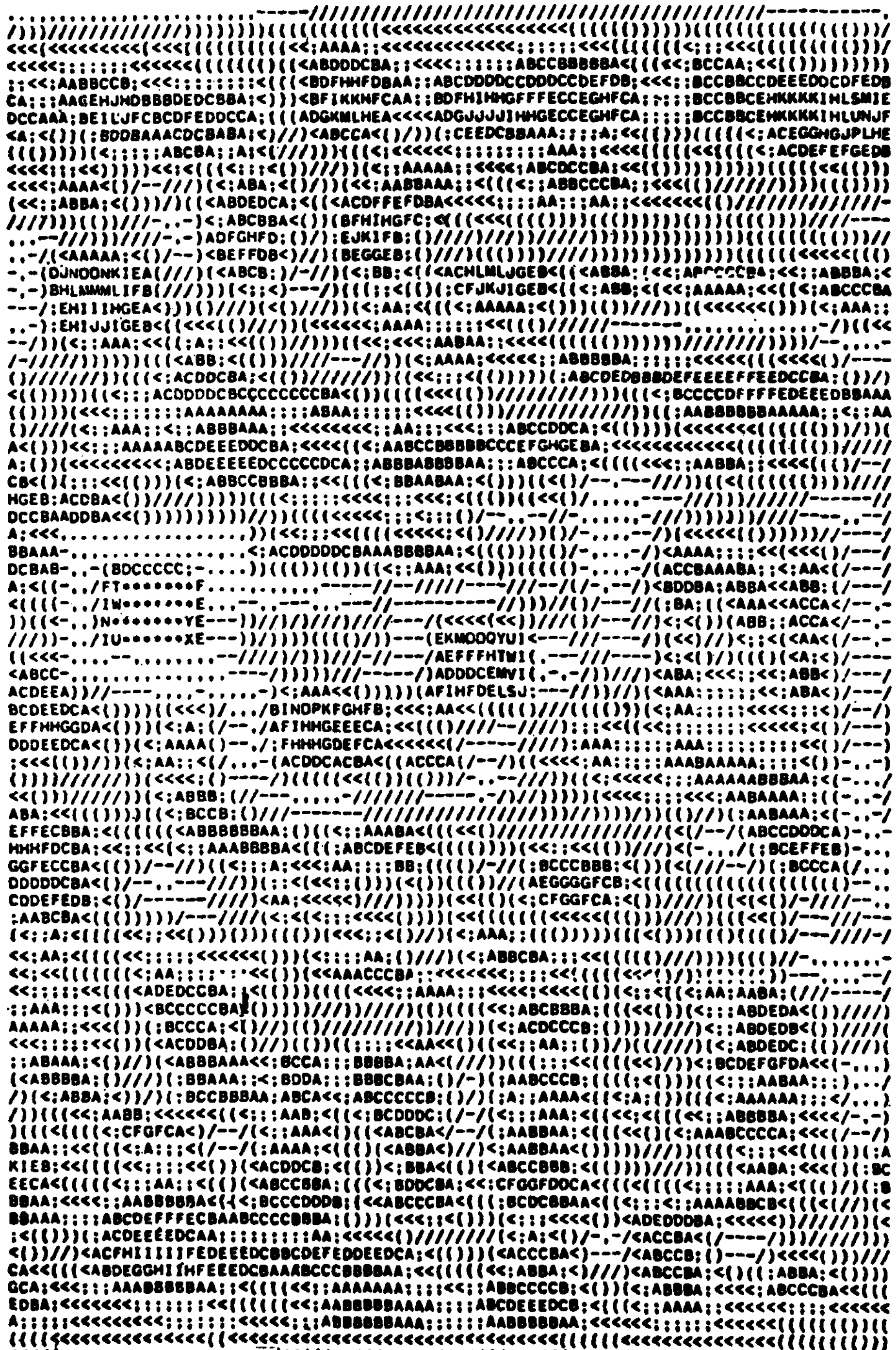

FIG 11 TABILS SCENE - FIRST MOMENT

# LOAL ALGORITHM PERFORMANCE ON TABILS IMAGERY

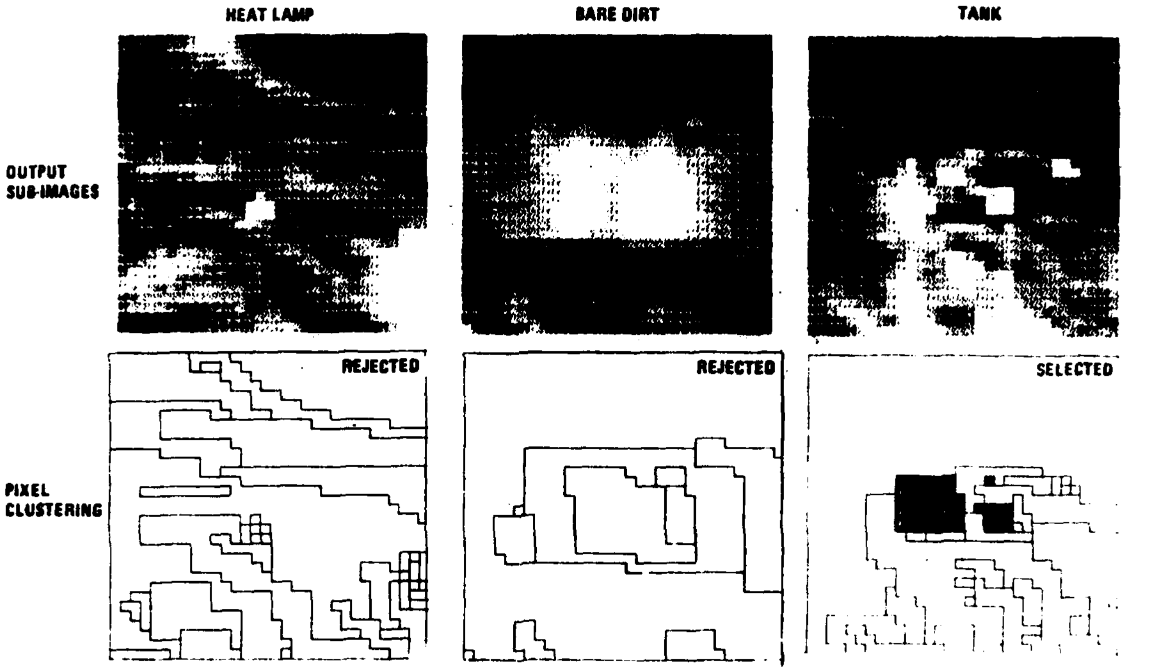


FIG 12